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Experience-Related Differences on Attentional Control in Cognitive Ageing

An Investigation of Bilingualism Effects on Flanker Conflicts in TFRs

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Abstract

Bilingualism has been argued to help maintain cognitive functioning in ageing by contributing to the cognitive reserve, the brain's functional adaptability and resilience against cognitive decline. Within this, the constant engagement with bilingual mechanisms to monitor multiple languages arguably leads to neurocognitive adaptations of attentional systems. Examining bilingual experience as a spectrum, and how these potentially link to variable individual outcomes in cognitive ageing remains understudied. Therefore, this study investigates the effect of individual differences in bilingual experiences on neurocognition in middle-aged adults and seniors. In the study, a non-linguistic flanker task was implemented while measures of both indices of brain activity through EEG and behavioral data were collected. In looking at the relation between differences in bilingual experiences and ageing, the study found that more balanced bilinguals were able to maintain their reliance on alpha activity in ageing, associated to the efficiency of attentional resources to focus on task relevant stimuli. Furthermore, the study found indications of a post stimulus increase in theta power related to cognitive control recruitment. The behavioral findings however, showed the opposite pattern as to what was expected, as subjects with more engagement in bilingual experiences showed a bigger effect of age on flanker task reaction times. Overall, these findings indicate that individual differences in bilingual experiences have a modulatory effect on neurocognition in ageing, potentially leading to better maintained cognitive functioning in cognitive decline.

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AD	Alzheimer’s disease
ACH	Adaptive control hypothesis
BAPSS	Bilingual Anterior to Posterior and Subcortical Shift
CR	Cognitive reserve
CRS	Cognitive reserve scale
DLB	Dementia with Lewy bodies
EC	Executive control
EF(s)	Executive function(s)
EP	Executive processing
ERD	Event-related desynchronization
ERP	Event-related-potential
ERS	Event-related synchronization
fMRI	functional magnetic resonance imaging
FTD	Frontotemporal dementia
IC	Inhibitory control
ITI	Inter-trial interval
ITCP	Inter trial phase coherence
LHQ3	Language history questionnaire
MSSSS	MacArthur scale for subjective social status
PASA	Posterior-anterior shift in ageing
PET	Positron emission tomography
PFC	Prefrontal cortex
SFFQ	Short form dietary questionnaire
TFR	Time-frequency representation
VaD	Vascular dementia

1 Introduction

The world's ageing population is increasing at a much higher rate than in previous years (WHO, 2021). An older population presents concerning issues regarding independence, health, and well-being, as older age is associated to greater risks of developing Alzheimer disease and other dementias as well as the health implications of normal age-related cognitive decline. Thus, identifying factors for maintaining cognitive health in ageing is an increasingly important public health matter. Research has found that neurocognitive outcomes in ageing are modulated by experience-dependent changes on cognition throughout the lifespan. Life experiences that are stimulating or effortful can potentially affect brain function in that they increase the cognitive reserve (CR), the brain's adaptability of functional processes, arguably leading to maintained cognitive functioning in neurocognitive decline (Bialystok, 2021.) Whilst it is fairly established that certain lifestyle factors such as physical exercise, a healthy diet, and education help maintain cognitive functions, these effects have more controversially been attributed to bilingual language processing due to its engagement with cognitive control systems. Moreover, various degrees of engagement in bilingual experiences might be reflected in cognitive processing differences throughout the lifespan. Therefore, an important direction in the field of cognitive science is to develop an understanding of underlying mechanisms related to bilingual language processing and identify the neurocognitive components of bilingual engagement in which potentially modulate the cognitive ageing trajectory. This study seeks to explore the effects of experience-based factors on attentional control in the early stages of cognitive ageing, which will contribute to the debate on neurocognitive bilingualism adaptations across the age spectrum.

2 Theoretical background

2.1 Cognitive Ageing and Bilingualism

2.1.1 Cognitive Ageing

With age, the brain's cognitive abilities progressively deteriorate. Cognitive abilities or functions refer to the essential mental skills in the brain used for everything from simple daily tasks to more complex tasks. Whilst certain cognitive functions such as vocabulary and general knowledge have been found to be maintained or to some degree even improve with age, other cognitive functions such as memory, the speed of cognitive processing and reasoning start to deteriorate in middle age (Salthouse, 2009, 2010). While some cognitive decline is to be expected in healthy ageing, some people will suffer a severe decline in cognitive functions, leading to dementia. The determinants of this cognitive deterioration related to ageing have yet to be fully understood, however, research has found that certain experiences and lifestyle factors potentially can delay the onset of cognitive decline by several years. Therein, the active use of two languages has been widely argued as one of the experiences that potentially result in a less steep deterioration of cognitive abilities in ageing as well as it has been suggested as a possible factor for delayed onset of dementia symptoms. Nonetheless, more research is necessary to understand the course of cognitive ageing and the determinants of individual differences therein.

Age-related cognitive decline represents a considerable variation of cognitive abilities across individuals in different stages of ageing. Therefore, determining the degree of cognitive decline in ageing presents issues in assessing whether the cognitive decline level is on an intra-individual level or comparative to a similar age group. Moreover, as previous life experiences highly influence cognitive outcomes throughout the lifespan, separating cognitive ageing from pathological ageing is not a straightforward process. This stems from the theory of a cognitive reserve (CR), in which a person with a stronger cognitive reserve better can withstand neuropathology; the normal deterioration of brain structure that occurs in ageing, injury, and brain diseases, in that brain pathology not necessarily leads to cognitive damage (Collaboratory on Research Definitions for Reserve and Resilience in Cognitive Aging and Dementia, 2022). CR holds the adaptability of functional brain processes, giving the brain the ability to actively compensate, show flexibility and make more effective and efficient use of neural networks (Stern et al., 2018; Stern, 2009). This entails that levels of cognitive functioning in ageing can be similar for people with different levels of brain pathology. The assumption is that CR is strengthened by experiences that are stimulating or effortful and that these experiences make the brain more resilient to non-pathological neurocognitive decline (Bialystok, 2017). This way, the presence of a certain amount of brain pathology could occur in one individual without any apparent signs of cognitive decline, whilst another individual with similar brain pathology but different cognitive experiences might see a severe decline in cognitive abilities (Brayne, 2007).

Normal cognitive ageing is regarded as the relationship between increasing age and cognitive abilities in the absence of disease. Cognitive decline approximately starts around the age of 45, though cognitive age effects have been found to be more prominent after the age of 60 (Salthouse, 2009; 2019). Intelligence such as general knowledge and vocabulary are thought to be relatively stable and to some degree even improve with age, however, increasing age also brings negative cognitive changes, amongst them, the deterioration of cognitive processing speed (Haranda et al., 2013: Salthouse, 2009). Processing speed is associated to motor control and refers to the speed of cognitive performance during both perceptual and automatic cognitive operations (Salthouse, 2000). Other domains which might exhibit cognitive decline are attention, working memory, and executive functioning (Carlson et al., 1995). Nonetheless, these cognitive changes may appear slower in individuals with certain life experiences. For instance, Manly et al. (2003) found that increased literacy (likely related to higher education), was linked to better maintained memory and language skills and thus suggested as a protective measure against cognitive decline in seniors in the absence of dementia. This is not limited to this study, as higher education has been linked to a slower decline of cognitive functioning in several other studies (e.g., Kramer et al., 2004; Stern et al., 1999).

Moreover, in looking at the characteristics of the ageing trajectory, it is important to distinguish between what is considered healthy ageing and abnormal ageing. For example, increasing age is one of the greatest risk factors for the development of dementing illnesses, with symptoms that are not part of normal ageing. Dementia is caused by brain cell damage that interferes with the brain's neural communication processes, triggering a decline in cognitive abilities severe enough to affect normal daily life functioning and behavior (Alzheimer's association, 2022). The most common reason for dementia is Alzheimer's disease, a progressive disease in which is believed to affect about 10% of the population over the age of 65, a percentage in which has been found to only increase with higher age

(Alzheimer's association, 2022). The progressive nature of Alzheimer's disease can be seen through worsening symptoms including cognitive dysfunction, confusion, memory difficulties, behavioral and mood changes, language impairment and more (Alzheimer's association, 2022). Though one can take certain preventive measures, there is currently not a pharmacological cure of dementia. Moreover, though research suggest that certain experiences can delay the onset of dementia symptoms, it has also been found that the following rates of cognitive decline after diagnosis appear more rapidly in dementia patients with a greater CR (Hall et al., 2007; Stern et al., 1999).

2.1.2 Bilingualism

Though somewhat controversial, there is growing evidence that dual-language experiences can affect cognitive performance and help maintain brain function and structure in cognitive ageing and brain pathology. Other lifestyle factors such as a healthy diet (Petersson & Philippou, 2016), higher education (Norton et al., 2014) and physical exercise (Diamond & Lee, 2011), have also been argued to maintain cognitive health in ageing and are generally not considered to be controversial. Bilingualism, which has often been considered a categorical variable in research, has shown to be a continuous experience with many markers (Leivada et al., 2020; DeLuca et al., 2019). In 1974, Oestreicher adapted a rather strict view of bilingualism stating that in order to be bilingual, one needed a "complete mastery of two different languages without interference between the two linguistic processes" (p. 9). Haugen (1953) had a different approach to the issue, defining bilinguals as individuals with the ability to "produce complete meaningful utterances in the other [second] language" (p.6). Grosjean (2010) however, understood bilingualism to be in an active state as he defined bilinguals as "those people who need and use two or more languages in their everyday lives" (p. 4). These views of bilingualism are all somewhat problematic, primarily as there are no ways to measure these linguistic levels in a consistent way. At what quantifiable point does one have complete mastery of a language? Is one not bilingual if the two languages are not being used equally in daily life? Another issue is that bilingualism highly has been conformed on linguistic proficiency alone, not including other affecting factors. Slabakova (2016) presents a more open approach to bilingualism as she defines bilinguals as having "the ability to use two languages" (p.92). With this, bilingualism does not equate to an equivalent linguistic ability or usage of two languages, however, the definition is subject to great variability.

Bilinguals are often considered in two groups, simultaneous (early) bilinguals, where one from infancy or a very young age acquire two languages, and successive (late) bilinguals, where a second language is learnt after already having acquired a native language. Within these two groups, there are many factors that influence linguistic and cognitive abilities, including the age of onset of a language, quality and quantity of linguistic input, acquisitional contexts, language background, as well as other social and socioeconomic influences. Thus, notably, the conflicting views of bilingualism only accentuate the spectrum it entails, and in considering its variability it seems evident that all bilinguals cannot be considered in under the same box in research, with the assumption that the bilingual experience of an individual from one side of the spectrum will equate to the same cognitive adaptations as an individual from the other side. Instead, bilinguals embody a group of individuals with diverse experiences, both linguistically and socially, with multiple dimensions accounted for.

2.1.3 The Effects of Bilingualism on Cognitive Decline

Various studies examining the effects of bilingualism on cognitive decline and brain disease have found that bilingual speakers show delayed onset of dementia symptoms by approximately 4 years in comparison to monolinguals (Salthouse, 2006; Bialystok et al., 2007). Bialystok et al. (2007a) looked at the cognitive effects of lifelong bilingualism in 184 dementia patients, in which 93 were bilingual. All the bilingual patients were fluent in two languages including English and had actively used both languages for most of their lives. The study found that the bilingual group showed delayed onset of dementia symptoms by 4.1 years compared to monolinguals. Other factors like differences in education and immigration status between the two groups were not significant. Additionally, Bialystok and colleagues looked at initially taken mini-mental state exams (MMSEs) after the onset of dementia symptoms, however, there were no significant differences between the two groups. This implies that though the bilingual group exhibited dementia symptoms later than monolinguals, following rates of cognitive decline developed similarly for both groups (Bialystok et al., 2007a). Therefore, Bialystok et al (2007a) speculatively suggest that bilingualism modify function for the brain to better tolerate pathology, while also claiming that environmental experiences such as bilingualism clearly interacts with biological factors to determine cognitive outcomes (Bialystok et al., 2007a).

Bilingualism and dementia studies commonly look at immigrant populations, bringing the validity on findings into question due to the uncertainty of environmental effects. However, Alladi et al. (2013) looked at 648 patients with different types of dementia diagnoses in which 391 were bilingual. The data were collected in India, a country with a great linguistic diversity, where multiple languages often are acquired simultaneously with code-switching being common (Alladi et al., 2013). This way, they were able to look at bilingualism as a part of daily life, motivated by socialization contexts and actively used by everyone, even the illiterate (Alladi et al., 2013). The study aimed at investigating the links between bilingualism and age of onset of dementia subtypes, while also taking other possible confounding factors such as education, sex, occupation, and living setting (urban, rural) into consideration. The study found that the delay in onset of dementia symptoms matched that of previous studies as they reported a delay of 4.5 years in bilingual patients compared to monolinguals. However, knowing more than two languages was not associated with any further differences in symptoms, speculated as being due to the already existing habit of dense code-switching (Alladi et al., 2013). All subtypes of dementia, including AD, VaD, FTD, DLB and mixed dementia showed a significant interaction with bilingualism, however, other individual differences such as education did not show any significance in the timing of onset of dementia symptoms. Illiterate bilingual patients were also found to have the same delay in the onset of dementia symptoms as the literate bilinguals (Alladi et al., 2013). With the 2013 study, Alladi et al. demonstrated the importance of considering various populations in different linguistic environments, though, the study also acknowledged that bilingual backgrounds should be examined more comprehensively with regards to individual variation (Alladi et al., 2013).

The process of maintaining health in ageing, healthy ageing, enables individuals to better maintain their functional capacities proceeding the cognitive changes related to normal ageing. In comparing healthy bilinguals and monolinguals, Bialystok (2007b) found that bilinguals were able to better maintain their cognitive functions in cognitive decline, as they were found to have a less steep deterioration of age-related cognitive decline. Using a Simon task, bilingual participants between the ages of 30 and 80 consistently exhibited a more efficient reaction time than monolinguals, however, from the age of 60 and above the reaction times of each group slowed down significantly, though, more rapidly for monolinguals. The study therefore suggested bilingualism to work as a protective measure for the decline of attentional processes in normal ageing (Bialystok, 2007b). A common interpretation is that bilingual language processing, in which actively monitor competition between jointly activated languages, belongs to a group of experiences that can increase CR and that way maintain cognitive functions in healthy ageing and possibly delay the age of onset of dementia symptoms, often specified as Alzheimer disease, in older adults (Bialystok et al., 2007; Craik et al., 2010; Anderson et al., 2020). Bialystok (2017) suggests that bilingual language processing engages domain-general attentional processes, and that this bilingual language recruitment of processes strengthens the overall attentional processes, and possibly improves CR (Bialystok, 2021). Altogether this results in the possibility of enhanced cognitive functioning in healthy ageing, and arguably also attributes to later onset of dementia symptoms in older bilingual adults. Various individual factors and life experiences help increase CR, with the critical feature for the contribution being that the experience is either stimulating or effortful (Bialystok, 2021).

2.2 The mechanisms of bilingualism

It has been widely argued that some experience-dependent changes on cognition can be attributed to bilingual language processing (Alladi et al., 2013; Bialystok, 2017, 2021; Anderson et al., 2017; Grundy et al., 2017). Findings within psycholinguistic research show that both languages of the bilingual brain remain active even in monolingual contexts, causing the bilingual to engage in neurocognitive processes to manage and select which language to use, and accordingly ignore the responses of the other (Kroll et al., 2014, 2015). Although the unused language of a bilingual speaker unconsciously influences the language in use, it is rare that bilinguals produce intrusion errors (Kroll et al., 2015). While research remains controversial, a common understanding is that practice in dual-language monitoring potentially leads to an adaptation of cognitive control abilities referred to as neurocognitive adaptations. However, as research show ambiguous results it is possible that these bilingual effects are restricted to the specific cognitive processes of certain bilingual experiences (Bialystok, 2016; Bak, 2015). Therefore, an important part of contemporary research is to identify the underlying cognitive mechanisms of different bilingual experiences which may lead to cognitive control adaptations. Notably, research in favor of these bilingual neurocognitive adaptations has been accused of publication biases, questioning the accuracy of set interpretations due to a preference of favorable results in early publishing (de Bruin et al., 2014). These biases have also been argued due to the low publication rate of research in which fails to show any significant results, and a greater quantity of favorable results being published.

2.2.1 The influence of Executive functions on bilingualism research

As all languages in the brain remain active at all times, there is a continuous need to manage them irrespective of contextual environment (Kroll et al., 2012). This additional cognitive demand of bilingual language processing has led to the assumption that the constant engagement with mechanisms required for bilingual language control may extend to adaptations in domain-general cognitive control. However, the nature of this mechanism has yet to be fully understood. The non-verbal cognitive tasks in which bilinguals' performance frequently has been reported as superior to that of monolinguals, have been prominent in the bilingual mechanism debate. These cognitive tasks, (e.g., the flanker task, the Stroop task, the go/no go task and more) use irrelevant stimuli in which must be inhibited to successfully complete the task. Due to the common nature of these tasks, the positive effects of bilingualism have widely been attributed to a transfer effect of a practice in bilingual language processing thought to recruit executive functions (EFs) to monitor activated languages and inhibit inappropriate responses of the nontarget language, ultimately leading to enhanced inhibitory control and better domain-general functioning. However, due to inconsistencies in research, the validity of such interpretations has also been questioned.

Inhibitory control belongs to a set of cognitive skills often referred to as executive functions (EFs) and has been defined as the ability to "control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure, and instead do what's more appropriate or needed" (Diamond, 2013). In the attempt to clarify the disposition of EFs, Miyake and colleagues (2000) proposed the Unity and Diversity model, stating that executive functioning is "comprised of three primary functions, inhibition, updating, and shifting." These three functions are essential mental functions in the brain for humans to successfully do normal daily activities, such as staying focused on something or shifting attention, cognitive flexibility, organizing daily life, controlling emotions, and self-control (Miyake et al., 2000; Diamond, 2013). Moreover, Diamond (2013) argued that inhibition, working memory, and cognitive flexibility, not only belong to a core group of EFs, but that these functions are trainable, and thus, can be improved.

Green (1998) proposed the inhibitory control (IC) model, suggesting the recruitment of a top-down inhibitory function to inhibit inappropriate lexical-semantic output so the correct linguistic production would occur free of any interference. In this model, the goal of the speaker is facilitated by a supervisory attentional system that employs lower-level language control (Green, 1998). This recruitment of IC was then further extended to also enhance inhibitory control in other task domains. However, in exploring factors such as the relative proficiency between languages, Cosa et al. (2008) revealed the complex nature of languages' selection processes, something in which inhibition alone could not account for. Therefore, in language activation in which they viewed as somewhat always being influenced by the non-target language, both inhibition and selection were needed (Costa et al., 2008).

Bialystok and colleagues (2004) compared bilingual and monolingual groups of old and young individuals using a manipulated version of the Simon task where participants had to inhibit misleading information. The study found that the bilingual groups had an overall better performance in the task, in that young bilingual adults outperformed young monolingual adults and older bilingual adults outperformed older monolingual adults. This was initially believed to be as bilinguals had better inhibition and overall enhanced executive functioning. However, inhibition theory could not explain why the bilingual groups had quicker reaction times in both congruent and incongruent conditions. Enhanced bilingual performance in both congruent and incongruent trials has been somewhat of a widespread find, thus, inhibitory control as mechanism for bilingualism adaptations on the brain has also met criticism for its inconsistencies.

To investigate what is believed to be the effects of added bilingual executive processing (EP) demands, Paap and Greenberg (2013) compared EP performance of bilinguals and monolinguals in different cognitive interference tasks. These tasks included anti-saccade; a task in which looks at eye movement during stimulus onset to assess the ability to inhibit saccadic eye movements, Simon task, Flanker task, and a color-shape switching task. Common for all tasks was that they made use of neutral and congruent conditions with a contrasting condition of incongruency demanding some degree of EF. The study found that the certain skills needed for tasks, such as inhibitory control in bilinguals, did not show consistent indicators of a greater bilingual performance across tasks, questioning the argument that improved performance on certain tasks result in domain general abilities (Paap and Greenberg, 2013). Moreover, in looking at non-linguistic interference tasks, Hilchey and Klein (2011) found that bilingual speakers outperformed monolinguals in both congruent and incongruent trials, though, arguably only the latter rely on inhibitory control. These findings therefore challenge the assumption that bilinguals' better performance on such tasks reflects an enhancement in inhibitory control.

2.2.2 The argument for adaptive control

Another influential theory for bilingual caused brain adaptations is the adaptive control hypothesis (ACH) proposed by Green and Abutalebi (2013). This theoretical framework differentiates the processes required for bilingual language processing based on interactional contexts as it posits that bilingual speakers adapt their cognitive control systems in accordance with communicative environments (Green & Abutalebi, 2013). Therein, three interactional contexts are distinguished, namely, single language contexts in which the bilingual speaker uses one language per environment, dual language contexts in which the bilingual speaker differs in language use per interaction within the same environment, and dense code-switching in which the bilingual speaker frequently alternate language use within the same conversation (Green & Abutalebi, 2013). This means that the demands needed for cognitive processes to control language use vary per interactional context. Interactional contexts in this sense are the patterns of communication within a set group of speakers and affect how language interference is resolved (Green & Abutalebi, 2013). Eight cognitive control processes are distinguished in the theory and described as differentially needed per interactional context. These processes include goal maintenance, interference control, salient cue detection, selective response inhibition, task disengagement, task engagement, and opportunistic planning (Green & Abutalebi, 2013).

The ACH further predicts how interactional contexts modulate language and cognitive outcomes with an emphasis on dual-language contexts in which they describe as demanding the highest linguistic and cognitive control such as goal maintenance, conflict monitoring, and interference suppression (Green & Abutalebi, 2013). This is as two or more languages are in a competitive relationship making it imperative to resolve interference to avoid using the nontarget language. However, opportunistic planning is of higher relevance for dense code-switching as it does not require equivalent inhibition of an entire language but rather allows for morphosyntactic integration with the necessity of high temporal control (Green & Abutalebi, 2013).

Principal to the notion of adaptive control is that different contexts will impact cognitive mechanisms differentially - in a way specific to each context. Therefore, as bilinguals often largely rely on one interactional context, this main context will have more influence on the cognitive outcome, meaning that bilinguals will show different neurocognitive effects context depending. However, the theory does not take other bilingual experiences into consideration, thus accordingly, a major implication for the theory is that as research shows that not all bilingual experiences will result in the same cognitive change, in presuming that all bilingual experiences (apart from interactional contexts) will result in this, also foresees ambiguous results as to the effects of bilingualism.

2.2.3 A Bilingual Adaptation of Attentional systems

In recent research, Bialystok and Craik (2022) argue that the inconsistencies of previous findings are not due to a lack of evidence for bilingualisms' influence on cognition, but rather a result of the framework that traditionally has been used to interpret the results (e.g., inhibitory control). Instead, they suggest attentional control as a mechanism that applies to a wider selection of cognitive tasks, overriding the EF processes of compositional models based on transfer effects (Bialystok & Craik, 2022). On this basis, behavioral differences between monolinguals and bilinguals cannot be attributed to enhanced inhibitory control, but rather to an adaptation of the attentional control system to manage bilingual language processing (Bialystok & Craik, 2022). Within this, Bialystok (2017, 250) argues that "lifelong bilingualism impacts a set of processes subsumed under the category of executive attention" (Bialystok, 2017, 250). Thus, it is this adaptation of attentional control systems, not transfer effects, that may extend to also benefit domain-general attention processes- including EFs, enhancing CR and cognitive task abilities (Bialystok & Craik, 2022; Bialystok 2012).

Attentional control in this sense describes a composition of functional processing operations in which cognitive tasks engage in various combinations depending on desired outcome (Bialystok & Craik, 2022). Thus, this arrangement of attentional control supports processing operations such as "selection, goal maintenance, temporary holding, coordination, engagement, and disengagement" and inhibit processing operations such as "interference suppression and response inhibition" (Bialystok & Craik, 2022). Bialystok and Craik (2022) argue that though experiences of bilingualism may result in more efficient use of attentional resources, it is unlikely that there will be an increase in the magnitude of resources. However, instead, various compositions of attentional control operations are applied by specific cognitive abilities defined as "coordination, flexibility, planning, monitoring, problem-solving, decision-making, and conflict resolution" (Bialystok & Craik, 2022), for effective and efficient functioning.

In research, a bilingual adaptation is not always seen in the task performance of young adults. This is typically interpreted as evidence against bilingual effects. However, the framework of attentional control entails that task domains such as reaction time data, might not always predict a cognitive difference in bilinguals (Bialystok & Craik, 2022; Abutalebi et al., 2015). Therefore, despite having equivalent reaction times, bilingual experiences might still modulate attentional control through goal maintenance. Moreover, young adults are not necessarily expected to perform better on simple or automatic executive functioning tasks, regardless of language experiences (Bialystok & Craik, 2022). Instead, control demands based of the complexity of the task domain along with cognitive control abilities, determines cognitive outcomes (Bialystok & Craik, 2022).

Regarding bilingual language use, the framework of attentional control offers what Bialystok & Craik regards as a compatible framework for ambiguous bilingualism research. This is bilingual language immersion modifies attention, creating stronger more flexible mental processes. This model of attentional control offers a better explanation of findings that do not fit in with other popular frameworks such as inhibitory control. For example, looking at 244 university students in which 122 were bilingual, Costa et al., (2009) used two manipulated flanker tasks to explore whether bilinguals showed greater efficiency in higher-demands of cognitive monitoring. The two flanker tasks were adapted and thus required either lower or higher cognitive monitoring of conditions. In the study, Costa and colleagues found that the performance of bilinguals and monolinguals were similar in the task with low-monitoring demands, however, bilinguals had an overall quicker reaction time on the high monitoring task regardless of condition. Conclusively, the study suggested that this was due to bilinguals' more efficient monitoring system. This occurrence of a quicker reaction time in both congruent and incongruent trials of the flanker task by bilinguals supports the suggested attentional control model. This difference in performance does not fit the view of inhibitory control, however, a bilingual adaptation of the attentional control could explain this overall more efficient performance of cognitively high-monitor demanding tasks.

2.2.4 Brain adaptations in ageing

In ageing, the brain appears to recruit anterior regions to better compensate for cognitive decline and brain pathology. Findings from functional neuroimaging studies suggest an age-related posterior to anterior shift in neural recruitment with a reduction in occipital neural activity combined with an increase in frontal activity (Davis et al., 2008). The posterior-anterior shift in ageing (PASA) model has therefore been suggested as an explanation for the functional compensation needed to deal with brain decline in ageing (Davis et al., 2008; Grady et al., 1994). This shift is further seen as several studies have found a positive correlation between cognitive performance and an age-related increase in the activation of the prefrontal cortex (PFC).

To examine whether PASA was an effect of ageing, or merely a reflection of a higher demanding task difficulty for older adults, Davis et al. (2008) used functional magnetic resonance imaging (fMRI) to examine brain activity in old and young adults. The study's results were in support of the PASA model as they found a reduction in occipital activity and an increase in PFC activity related to ageing. This activity was found even in conditions in which differences in difficulty were removed. The interpretation was therefore that this posterior to anterior shift in ageing worked as a functional compensation to age-related decline as there in older adults was a negative correlation between occipital reduction and a PFC increase, but a positive correlation between an increase in PFC activity and cognitive task performance (Davis et al., 2008). Moreover, Grady et al. (1994) conducted a positron emission tomography (PET) study that used faces and places to investigate the perception abilities of old and young adults. The study found older participants to have weaker neural activity in occipitotemporal regions but greater activity in anterior regions than young adults, also including the PFC. Moreover, in using the same task, Reuter-Lorenx et al. (2000) found links between faster working memory task performance and the recruitment of bilateral PFC regions in seniors.

Grundy, Anderson, and Bialystok (2017) extended the framework of PASA as they introduced the Bilingual Anterior to Posterior and Subcortical Shift (BAPSS) model. The model links bilingualism to efficient brain recruitment as it posits that bilinguals have a greater recruitment of posterior subcortical regions and a smaller recruitment of frontal regions (Grundy et al., 2017). Therein, bilinguals recruit more resources from posterior regions responsible for motor functions. As this pattern for neural recruitment has been found in studies in which no behavioral differences have been found, it is therefore argued that the recruitment pattern is not a reflection of dedifferentiation but instead a reflection of efficiency (Grundy et al., 2017). Therefore, if there is a shift from posterior to anterior regions in ageing, the BAPSS model shows a reliance upon posterior regions in ageing for lifelong bilinguals. Thus, maintaining posterior brain recruitment in ageing potentially makes more effective use of neural resources, leading to a delay in age-related cognitive decline.

2.3 Measures of bilingual effects

2.3.1 Behavioral interference tasks

Behavioral interference tasks such as the Flanker task (Eriksen & Eriksen, 1974), go/no-go task and Stroop task (Stroop, 1935) have widely been used to measure mechanisms of cognitive control as they look at participants' ability to monitor conflict by suppressing irrelevant information in a set context. The flanker task presents the participant with stimuli in the form of arrows, letters, or colors; the participant then reacts to a central target which is surrounded by 'flankers' used for distraction in congruent, incongruent, and neutral trials. The goal is to as quickly and accurately as possible click a left or a right button depending on the central target. Participants typically have a less accurate and slower reaction time with incongruent stimuli. Previously, this suppression of responses has been reported as a measure of inhibitory control, however, reaction time data is not a deflection of the mechanism used for the task, but rather a tool to measure the effect or outcome of cognitive operations. Therefore, as there are difficulties in identifying mechanisms related to specific tasks using behavioral data alone, one can expand the data for these tasks by performing them while using neuroscience measures to see how certain tasks affect brain processes and examine experience-dependent processing differences. Notably, though these tasks are popular for bilingualism and cognitive research, it has also been argued that these behavioral interference tasks are insufficient in measuring cognitive mechanisms.

2.3.2 EEG

One way to measure the deployment and efficiency of attentional control is by using electrophysiological measurement tools. Electrophysiological measures can provide an intricate picture of the neural activity related to cognitive processes (Dickter & Kieffaber, 2014). This is as the human brain is built up of large quantities of neurons that communicate through small electric charges or impulses. Electroencephalography (EEG) is a non-invasive way of capturing the brain's electrical activity through the use of a cap of electrodes placed on the scalp (Luck, 2014). The electrodes record the electric fields produced by neural responses to given tasks or conditions. The method's high temporal resolution allows the recordings to capture precise measurements of the changes in neural activity associated to given stimuli, meaning that accessing the time-course of task-relevant cognitive processing becomes possible, as well as creating the ability to separate component processes before, during and after onset of stimulus (Dickter & Kieffaber, 2014). The various electrodes show the placement of the scalp in where electrical activity originates; however, it cannot show depths of the electrical charges nor does is measure individual neural impulses. Instead, it measures the scalp's electrical fields that are produced when millions of neurons collectively communicate (Luck, 2014).

2.3.3 Time Frequency Representations

EEG data can be analyzed and interpreted in many ways, a common method being through event-related-potentials (ERPs). However, although ERPs have been found to show significant insights, they only deflect the neural activity locked to a set event on the assumption of synchronous component signals across trials (Luck, 2014). Time frequency representations (TFRs) on the other hand, allow for a more inclusive interpretability of neural activity. Time frequency data is found by looking at brain oscillations across different frequency bands. Certain experiences such as bilingualism have been found to modulate brain activity seen through changes in specific frequency bands during both resting state and task performance.

Alpha band activity ranges from approximately 8 to 12Hz and is considered the dominant band frequency (Klimesch, 2013; Van Diepen et al., 2019). Modulation in alpha power generally occurs with relaxation and can reflect indices of brain activity during both resting state and task performance. Alpha activity can be seen through either an increase or decrease of power, often referred to as event-related synchronization (ERS) and desynchronization (ERD) (Van Diepen et al., 2019; Klimesh, 2012). Alpha power has been related to changes in attention following stimulus onset (van Diepen et al., 2016), inhibition of irrelevant information (Klimesch, 2012; van Diepen et al., 2019), and reorganization of attentional resources to improve task performance (van Diepen & Mazaheri, 2017). A study conducted by Bice et al. (2020) compared the brain activity of bilingual and monolingual subjects during resting state. The study found bilinguals to not only have greater alpha power, but that this alpha band activity was modulated by aspects of bilingual language control including more frequent L2 use, higher L2 proficiency, and age of L2 onset. In the same study, bilinguals were also found to have greater frequency connectivity in alpha and beta bands (Bice et al., 2020). Herein, alpha was argued to signify language control as part of the inhibitory control framework. Thus, the coherence and power of alpha activity was suggested to shape neural networks to achieve better bilingual language control due to the constant engagement of inhibitory alpha mechanisms for bilingual processing (Bice et al., 2020). Klimesch (2012) argues that alpha band oscillations reflect inhibition and timing related to suppression and selection of attention (Klimesch, 2012). Moreover, the extent of alpha activity changes with age as older individuals between the age of 60 and 80 years old have been found to have an approximate alpha decrease of 1Hz, this decrease has also been related to neurological diseases (Klimesch, 2012). In higher demands of task performance, alpha power desynchronization (suppression) is associated to cognitive control, however, in the theta band, the amount of theta synchronization is associated with effective cognitive performance (Kilmesch, 2012).

Theta band activity ranges from approximately 4 to 8Hz and has a central role in working memory processes to monitor interference during the course of information processing (Kilmesh, 1999). In previous research, this has been seen through how cognitive interference tasks' higher processing demands yield an increase in theta band activity, showing that an additional recruitment of theta power is needed to resolve conflict in incongruent trials of tasks. On this basis, theta band amplitudes are proposed as a way to measure cognitive control engagement, and the recruitment of cognitive control processes, (Nigbur et al., 2011). Looking at bilingualism effects on resting state brain activity, Pereira Soares et al. (2021) found theta, alpha and gamma frequencies mean coherence measures to be modulated by a greater usage in the non-societal language. Furthermore, in investigating flanker task reaction time data and EEG amplitudes, Wang et al. (2017) compared athletes of interceptive sports that require skills in reaction speed and precision in unpredictable settings (badminton), to athletes of track and field. Their hypothesis was that the players of interceptive sports would have quicker reaction times and show higher theta band amplitude due to higher motor expertise. However, though, the players of interceptive sports were found to have overall quicker reaction times, both groups were found to have similar theta band amplitudes (Wang et al., 2017). Nonetheless, the players of interceptive sports did show a higher theta inter trial phase coherence (ITCP), overall suggesting that these differences were a result of training-induced adaptations (Wang et al., 2017).

2.4 Dynamicity of bilingualism and individual differences

The bilingual effects on neurocognition debate has predominately centered on monolingual versus bilingual comparison. However, bilingualism is a dynamic experience, not a categorical variable, making individual variation within the bilingual experience, such as environment, language context, frequency of use, age of onset and proficiency, key in predicting specific experienced-based changes on cognition (Luk & Bialystok, 2013; DeLuca et al., 2019). DeLuca et al. (2019) suggest a bilingual-centric approach to capture and unpack the dimensions of potential bilingual-based adaptations on the brain. This way, bilingualism represents not one experience, but a range of experiences that impact brain structure and function on different levels.

To examine the potential neurocognitive adaptations of bilingualism, Pereira Soares et al. (2022) looked at the brain oscillations of early bilinguals (heritage speakers) and late (successive) bilinguals performing a flanker task. Whilst the study did not find any behavioral differences between groups, apart from greater flanker task accuracy of the late bilinguals, individual differences in oscillatory dynamics were found. Therein, theta increase, and alpha suppression were the frequency bands that were most affected by individual bilingual experiences. These results were interesting in that the cognitive control differences were found to be modulated by bilingual experiences distinctly for each group - no between group differences were found. For the heritage speakers, a negative correlation was found between age and amplitude in the theta frequency band. For the late bilinguals however, age of second language attainment and age predicted the amplitude in the alpha frequency band. Therefore, the study suggests that bilingual experiences modulate the recruitment of neural oscillatory dynamics, however, these adaptations manifest differently between bilinguals (Pereira Soares et al., 2022). For example, the onset of bilingualism appears to connote the outcome of individual differences in brain recruitment (Pereira Soares et al., 2022).

DeLuca et al. (2020) conducted an fMRI study with participants performing a flanker task to explore potential bilingual effects on executive control (EC). In their study, different bilingual experiences such as time since L2 attainment, L2 immersion, and degree of active bilingual language use were accounted for. The study found different bilingual experiences to influence the activation of distinct brain regions, indicating changes in neural recruitment associated to EC depending on differences in bilingualism experiences (DeLuca et al., 2019). Guzmán-Vélez & Tranel (2015) identify L2 age of onset, L2 language proficiency and frequency of use of both languages to be important factors for neurocognitive effects. Altogether, this implies that it is distinct bilingual experiences that potentially modify cognitive control, providing an explanation for the ambiguous results of research on bilingualism as a uniform category. Experience related neurocognitive effects have also been attributed to individual differences such as socioeconomic background (Marton, 2016), education (Guzmán-Vélez & Tranel, 2015), musical training (Hanna-Pladdy & MacKay, 2011), a nutritious diet (Petersson & Philippou, 2016), and physical exercise (Diamond & Lee, 2011), making it important to control for these factors in bilingualism research.

On the basis of the continuum of bilingualism experiences and individual differences, Leivada et al. (2020) argued that the phantom-like appearance of neurocognitive bilingualism effects needs to be further researched in a modified way and suggests multi-lab collaborations as a way to gain greater understanding of the conditions in which potentially affect neurocognition. Multi-lab work would help account for linguistic trends across groups as well as aiding in sample size and power of bilingualism analyses. Their suggested path for further research also distinguishes bilingualism as a continuum of experiences while emphasizing the importance of accounting for environmental factors and other individual differences. Within this, controlling for critical confounding variables such as L2 onset, frequency of use and proficiency, economic and social status, as well as code-switching, are of particular importance as it is likely that bilingualism compete with other sources of contributes for adaptation (Leivada et al., 2020).

A bilingual-centric approach to investigate the variability of cognitive changes is in itself a new approach to neurocognition research. Moreover, middle age is a critical time that signifies the onset of cognitive decline in ageing. Therefore, applying the spectrum that is bilingual experiences to the cognitive ageing trajectory allows for the investigation of the potential differential cognitive outcomes in ageing conditioned by individual differences in bilingual experiences. A combination in which has not yet been explored. This way, by collecting extensive data on individual bilingual language experiences and cognitive background, alongside EEG recoding during task performance, prospectively reveals the correlation of experience-related differences on the neurocognitive profile in ageing.

2.5 The present study

This thesis aims to investigate how experience-based factors such as differential engagement in bilingual language experiences and individual differences affect attentional control in cognitive ageing. The present study therefore looks at data from bilinguals with various degrees of engagement in their non-societal language. Working from the findings of recent research, the study does not engage in a monolingual versus bilingual distinction in cognitive control efficiency and deployment but does instead seek to understand how differences in bilingual language use, such as active bilingualism, can be determinative for potential brain adaptations. This is investigated using a non-linguistic flanker task in combination with an EEG recording. The use of EEG is invaluable to the study in that it gives insight to the physiological changes of brain activity during flanker task performance.

2.5.1 Research question

1. What is the effect of bilingual experiences on attentional control in middle-aged adults and seniors?

2.5.2 Predictions

1. Active bilingual language use will adapt attentional control in cognitive ageing and result in a more efficient flanker task performance. This prediction builds on the research that bilingualism represents not one experience, but a range of experiences that differentially affect cognition. Therein, more active use of a second non-societal language will adapt attentional control resulting in more efficient or maintained attentional control abilities in ageing which will be seen through a decreased slowing of reacting time in the flanker task in ageing. Younger age and a healthy lifestyle may also contribute to the efficiency of attentional control needed for the flanker task.

2. Extent of active bilingualism, age and individual differences will correlate to neural oscillation amplitude in theta and alpha band activity in which greater active bilingual language use will result in more efficient deployment of neural resources. My prediction is therefore that more active second language use will result in more theta band activity and a smaller alpha desynchronization; thus, I predict a maintained reliance upon posterior regions for cognitive resources in ageing - associated to the BAPSS hypothesis. However, subjects with less active second language use with

higher lifestyle scores may potentially show the same adaptations on attentional control.

3 Methods and Materials

3.1 Participants

20 participants were recruited for the study (male = 7, mean age = 56.8, age range = 45-82, see appendix B) through social networking, social media, and notice boards. All the participants had Norwegian as their only native language with English as a second language. The participants were cognitively healthy left- and right-handed individuals over the age of 45 with normal or corrected-to normal vision. They reported no prior history of brain-injury or neurological disorders and were at the time of participation not using any psychotropic medications. Participants were compensated for their time with a 500 NOK gift card.

3.2 Materials

A non-linguistic flanker task was used for the experiment. The flanker task stimuli were presented using Presentation® (Neurobehavioral Systems) software and displayed in white on an otherwise black screen using a 27-inch monitor. The instructions for the task were given in Norwegian Bokmål, the dominant form of written Norwegian in Tromsø, the location of the experiment. The task started with 12 practice trials to ensure the participants' understanding of the previously given instructions. The practice trials consisted of four congruent trials in which all arrows pointed the same way (see figure 1), four incongruent trials in which the central target pointed in the opposite direction to the flanking arrows (see figure 2), and four neutral trials in which only one arrow was shown on the screen pointing either left or right (see figure 3.) The practice trials provided real-time feedback on each trial using either a green check mark to indicate that the answer was correct, or a red X to indicate that the answer was incorrect. The manual responses were recorded using two buttons placed with a horizontal distance of 20 cm from one another. The experimental part of the flanker task consisted of two blocks of 120 trials. The 240 trials were split equally between the three conditions (80 per condition) in a randomized order. A central fixation cross in which allowed the participants to focus their attention on the middle of the screen was displayed for a randomized duration of 400-1600ms preceding each trial. Subsequently, a complete black screen appeared for 200ms before the flanker stimulus was displayed. The flanker stimulus was shown until the participant responded or for a maximum time of 1500ms. Thereafter, to prevent any transfer effects between conditions, a blank 2000ms inter-trial interval (ITI) was shown.

Figure 1 Left congruent stimulus

Figure 2 Left incongruent stimulus

Figure 3 Left neutral stimulus

3.3 Procedure

The study was approved by the Norwegian Centre for Research Data (NSD.) Participants were initially guided through a contact questionnaire to confirm eligibility for the study before they were instructed to read and sign a consent form. The informed consent form was available in both Norwegian and English and stated in short terms the purpose of the project and the participants rights, while also assuring that no negative consequences would arise if choosing to withdraw from the study. Participation consisted of filling out a Language History Questionnaire (LHQ), short form dietary questionnaire (SFFFQ), MacArthur scale for subjective social status, a Cognitive Reserve Scale (CRS) and partaking in an EEG recording while performing the flanker task. Following Grosjean (1998) argument of controlling a bilingual's language mode to prevent the subjects from having full activation of both languages, the participants of the study were only exposed to Norwegian, their native language, during the experimental part of the project. Upon arrival, participants were capped with a 32 Channel Wet-sponge R-net cap for LiveAmp (Brain Products, 82205 Gilching, Germany.) They were then seated in front of a monitor with an approximate distance of 55-70 cm in a sound-attenuated room with dim lighting. The stimuli were presented using Presentation® (Neurobehavioral Systems). The participants were instructed to read the instructions given on the screen and had the option to ask questions between every interval of the task. The participants were instructed to press either a left or right button using the corresponding hand, stimuli depending. If the central arrow pointed to the right, the participant was instructed to press a right-side situated button using their right hand, if the central arrow pointed to the left the participant was instructed to press a left side situated button using their left hand. The participants were recommended to take a short break in the middle of the task after the first block of 120 trials. The participants were further told to respond as fast as possible while still maintaining high levels of accuracy.

3.4 Data collection

Electrophysiological responses were recorded using a 32 Channel Wet-sponge R-net for the LiveAmp amplification system for EEG (Brain Products, 82205 Gilching, Germany), following the 10-20 system of electrode placement and recorded from ground (Fpz) (Brain Products, 82205 Gilching, Germany). The electrodes were all made to be within an impedance value of 100k, with the ground and reference points having an impendence of less than 50k. Brain Vision recorder by Brain Products was used for collection and data were collected at a sampling interval of 2000 with a sampling rate of 500Hz.

3.5 EEG Data pre-processing

The collected EEG data was initially processed using Brain Vision Analyser 2.0 (Brain Products GmbH). A band pass filter of 1-55Hz and a 50 Hz notch filter was applied to the data. Thereafter, the signal was segmented relative to the reference marker position, starting at -1000ms before stimulus onset to 2000ms post stimulus onset, making up 240 segments of 3000ms seconds per dataset. The data were baseline-corrected with a -100ms to 0ms pre stimulus interval. Next, an independent component analysis (ICA) for ocular correction was implemented on all channels, identifying and removing blinks and other strong eye movements. ICA was performed on the data with the Brain Vision 2.0 Informax Restricted ICA algorithm. Other artifacts such as drifts were then removed manually. Signals with abnormal noise were interpolated using spline topographic interpolation (a maximum of two electrodes were interpolated per dataset). Lastly, all channels of the data were given a new reference. The re-referenced data were then exported to MATLAB where further processing and analysis were performed using the Fieldtrip toolbox (Oostenveld et al., 2011). The Fieldtrip computations of TFRs followed the design of Pereira Soares et al. (2022).

Power was calculated in the 2-45 Hz band frequency range, allowing for the investigating of theta band (4-7 Hz), alpha band (8-12 Hz), low beta (13-20 Hz), high beta (21-30 Hz) and gamma (31-45 Hz). The trialfun function was used to compute segments of 500ms, additionally, a time window from - 0.75 pre stimulus to 1.25 post stimulus onset in steps of 50ms and 1 HZ was applied to the data. A Hanning taper was used and TFRs were computed as a relative change of the -500 to -100ms baseline. Lastly, TFRs were averaged for each of the experimental conditions, as well as each subject. The flanker effect found in the difference between incongruent and congruent trials, was used for the statistical analyses moving forward.

3.6 Data analysis

For the analysis, the SFFQ, MSSSS and CRS questionnaires were scored and scaled into one lifestyle score. The LHQ3 was further used to calculate a multilingual language diversity (MLD) score, as first introduced by Gullifer & Titone (2018) and done by Li et al. (2019).

The MLD score has a range between 0 and 2 and calculates language diversity based on both language proficiency and usage in up to four languages. The behavioral flanker task reaction data was then adapted for RStudio and merged into one table. Using the trimr package (Grange, 2015), neutral trials, incorrect trials, and trials with a reaction time less than 150ms and a maximum of a 2.5 above the standard deviation per dataset, were removed. This resulted in the removal of 145 trials (excluding the 1600 removed neutral trials). A linear mixed effects model was conducted using lme4 package, with the following formula

1. lmer(rt ~ Age*condition + lifestyle + (1|Subject)

Thereafter, a follow up model was computed, adding in multilinguistic diversity scores using the formula

2. lmer(rt ~ Age*condition*MLD + lifestyle + (1|Subject)

Using ANOVA, these models were compared to ensure that the follow up model would result in added information.

3.7 TFR analysis

For the TFR analysis, a cluster-based permutation analysis was used to identify relevant time-frequency clusters. To do this, a 1000 -randomizations cluster-based permutation using the Monte Carlo method was done. Clusters were found in the 4-7 Hz theta band frequency (positive theta cluster) in the time window 0.4 to 0.65, and in the 8-12 Hz alpha band frequency (negative alpha cluster) in the time window 0.6 to 0.95 post stimulus onset (see appendix C, D). These clusters were average over time, finding the greatest set of electrodes for the selection of frequencies of interest to extract TFRs, resulting in the application of a 0.525ms (theta) and 0.775ms (alpha) post stimulus extractions. The TFRs were then put into a robust linear regression model in RStudio, using the Robustbase package (Maechler et al., 2022). The following formulas were computed for each TFR. Looking at the effect of age and lifestyle on theta power. And then, to examine the modulations of theta power, a model including the interaction of Age and MLD in addition to a main effect of lifestyle factors was computed.

3. lmrob(theta_ROI_pos ~ Age + lifestyle)
4. lmrob(theta_ROI_pos ~ Age*MLD + lifestyle)

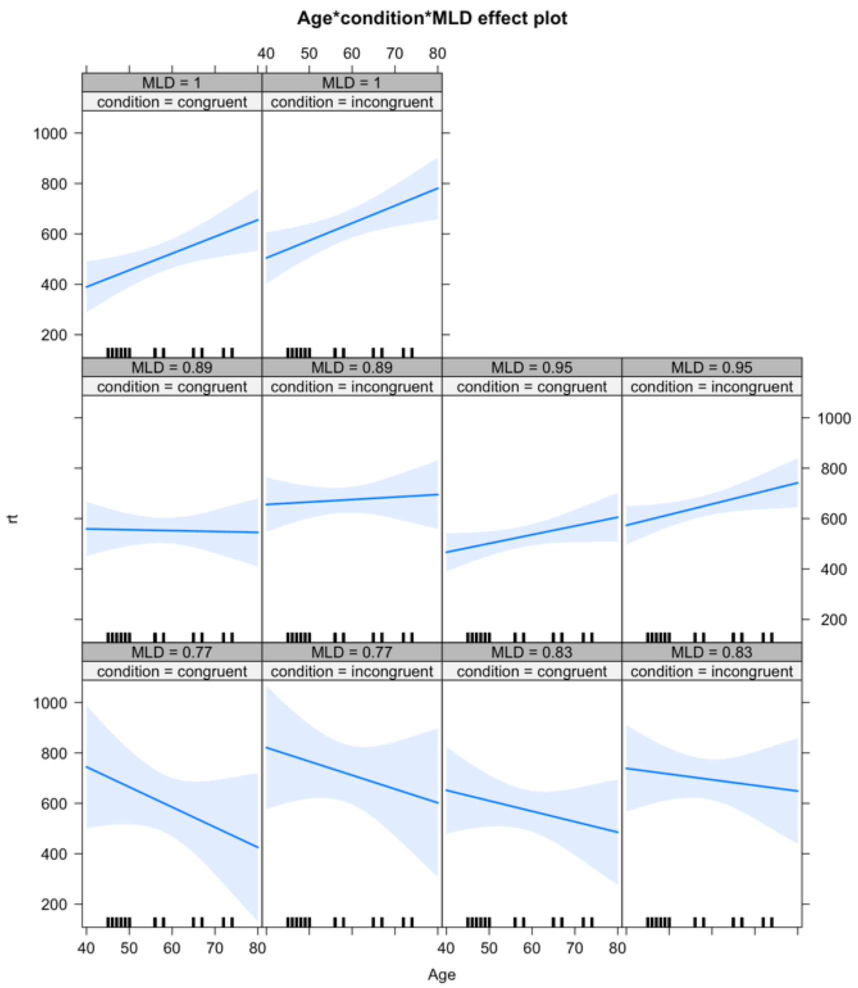
ANOVA was again used to compare the models, to ensure the contribution of the more complex model. The same code was used to the extracted alpha representations.

4 Results

4.1 Behavioral results

Reaction times measured in milliseconds were faster in the congruent condition (mean = 525.3, range = 399.9 to 719.9) than in the incongruent condition (mean 644.1, range = 497.1 to 819.4) (for distribution see appendix E). The behavioral analysis showed a significant intercept (congruent condition) (Std. Error = 1815.612, p = 0.035). The main effects of MLD (Str. Error = 1903.14, p = 0.048), and lifestyle (Std. Error = 42.047, p = 0.473) on RT, were also significant. The model further showed significant interactions between Age and Condition Incongruent (Std. Error = 4.557, p = 0.028), and Condition Incongruent and MLD (Std. Error = 277.705, p = 0.045). Moreover, the model showed a significant three-way interaction between Age, Condition and MLD (Std. Error = 5.760, p = 0.041). This three-way interaction is visualized in figure 4.

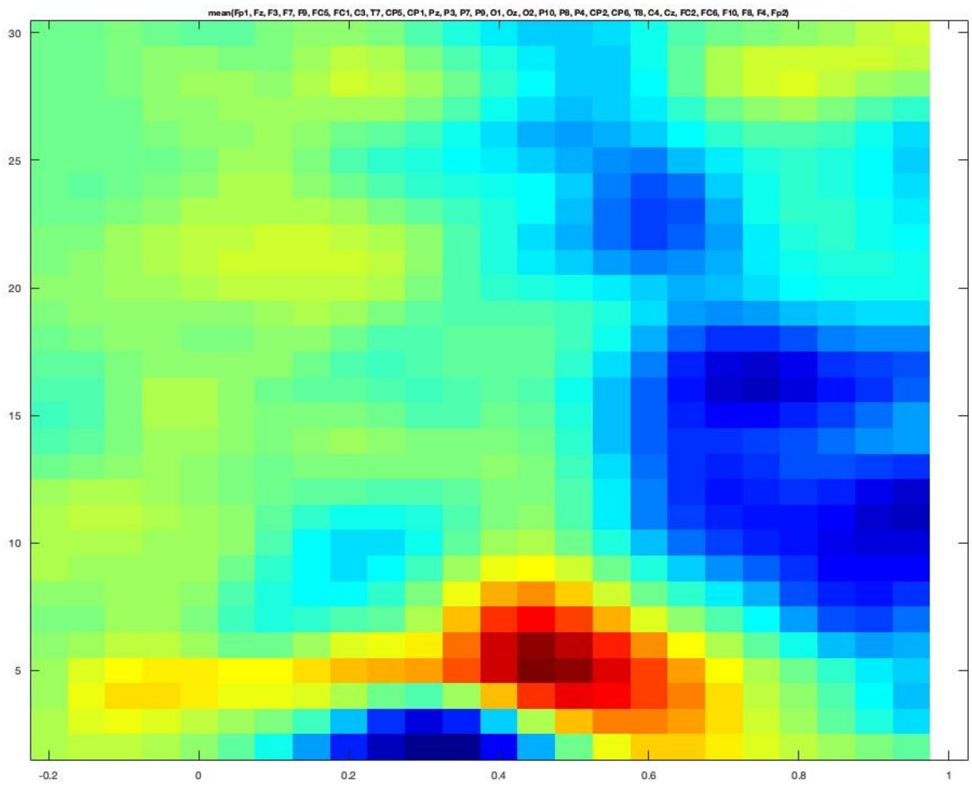
Figure 4 Three-way interaction plot, Age, Condition, MLD



4.2 EEG results

The distribution of the mean across channel flanker effect power is visualized in figure 5.

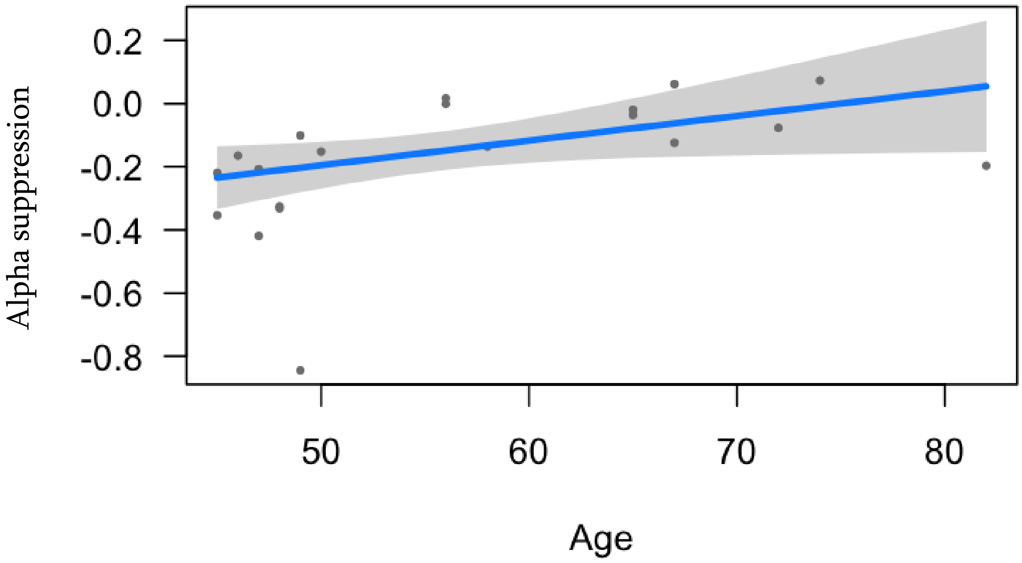
Figure 5 Incongruent/Congruent difference



4.2.1 Alpha suppression

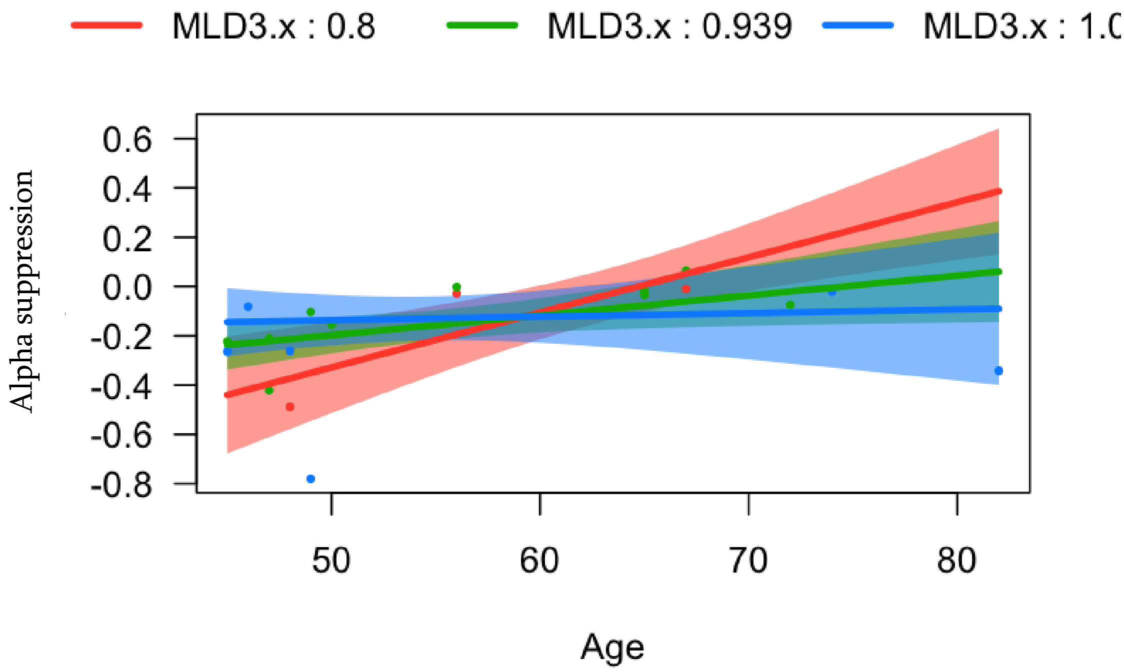
Significant effects were found in the alpha (negative cluster) frequency band. In looking at the results, there was a significant effect of Age on alpha suppression (Std. Error = 0.042, p = 0.024). This effect is visualized in figure 6. The plot shows that with increasing age, the incongruent – congruent difference in alpha suppression (desynchronization) decreases. Previously, alpha suppression has been linked to posterior functional recourses which have been found to undergo a shift to anterior regions in cognitive ageing.

Figure 6 Effect of Age on Alpha Suppression



Moreover, the intercept (condition) showed a significant effect on alpha suppression (Std. Error = 2.518, p = 0.025). The individual differences in bilingual language experiences, MLD, did also exhibit a significant effect on alpha suppression (Std. Error = 2.724, p = 0.042). The interaction effect between Age and MLD on Alpha suppression also reached significance (Std. Error = 0.045, p = 0.0395). This interaction is visualized in figure 7.

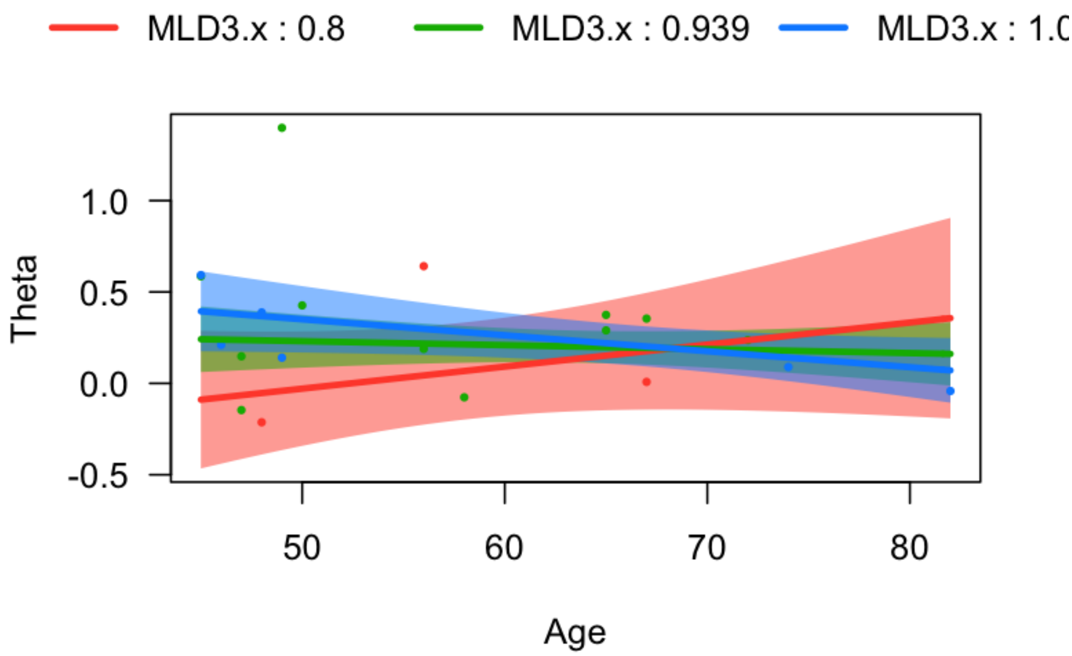
Figure 7 Interaction effect of Age and MLD on Alpha Suppression



4.2.2 Theta

The results of the theta (positive cluster) band frequency analysis were non-significant. However, MLD arguably showed a trending effect on predicting power in the theta frequency (Std. Error = 0.05757. *p* = 0.0633). This interaction is visualized in figure 8.

Figure 8 Interaction effect of Age and MLD on Theta power



5 Discussion

The present study aimed to investigate the spectrum of bilingual-caused differences on attentional control in ageing adults and seniors. Whilst previous research has engaged in flanker conflicts to measure cognitive bilingualism effects, looking at bilingualism as a dynamic experience with differential outcomes on cognition in ageing, remains an understudied subject. Therefore, to investigate these potential neurocognitive bilingualism effects in normal ageing, a non-linguistic flanker task was implemented and performed by adults and seniors while both behavioral reaction time data and indices of brain activity were recorded using EEG. The study found a post stimulus onset of both theta and alpha band activity. Within this, what was seen was a theta band increase followed by alpha band suppression. Importantly, this shows that the data is an index of attentional demands and not merely gating of task irrelevant regions. Thus, theta activity signifies the recruitment of functional resources, whilst alpha activity signifies the allocation of attention relevant to the task at hand. The behavioral data showed the opposite of what was expected, indicating that with increased multilinguistic diversity, reaction time does not show a slowing down in ageing, instead this was seen in subjects with lower multilinguistic diversity. This is likely to be due to the narrow range of MLD scores of 0.7737966 to 1.0057291 of a possible range of 0-2, meaning that all subjects were quite bilingual. It could also be a power issue, as the study only contained 20 subjects in which only a few were seniors, making it important to interpret all results with caution.

5.1 Behavioral results

To investigate the relation between individual differences and flanker task reaction times, a linear mixed effects analysis was conducted. The behavioral flanker task response times were significantly slower in the incongruent than the congruent condition indicating that the task was performed as expected. The base model showed a significant effect of age, in that participants performed slower with age. This correlates to previous literature, in that reaction abilities worsen with older age (Salthouse, 2015). However, in examining the interaction between reaction time, age and MLD, people of higher MLD showed a more significant effect of age on reaction time differences. Thus, what was seen was that irrespective of condition, participants tended to get slower as age increased, which was more pronounced with higher MLD. This is the opposite as to what was predicted, as participants with a higher MLD score, meaning they were more balanced bilinguals, were hypothesized to show a decrease in slowing with age. Other studies such as Pereira Soares et al., (2022) failed to find significant reaction time data differences between bilingual groups, yet differences were found in brain recruitment. Moreover, attentional control adaptations depend on the interaction between task demands and individual cognitive control abilities (Bialystok and Craik, 2022). Therefore, consistent cognitive adaptations are not expected across all task domains as attentional effectiveness manifests differently throughout the lifespan and does not indicate enhanced performance on specific tasks. However, this still does not explain why the subjects with increased MLD were found to have a bigger effect of age than subjects with lower MLD. Another theory could be that the participants have yet to go through those stages of cognitive decline in which benefits from a strengthened CR. Nevertheless, the effect of MLD on age is difficult to interpret due to both the narrow MLD range and low statistical power.

5.2 EEG results

To investigate how individual differences in attentional control relate to differential engagement in bilingual language experiences, a cluster-based permutation test was implemented. Therein, the flanker effect (incongruent/congruent difference) power values from the alpha and theta frequency bands were extracted and regressed with multilinguistic diversity scores to examine how differences in neural activity attend to conflict resolution. Positive theta clusters were found 0.4 to 0.65ms post stimulus onset and negative alpha clusters were found 0.6 to 0.95ms post stimulus onset. This is in accordance with previous research on the oscillatory dynamics of interference tasks, such as Nigbur and colleagues (2011), who reported increased theta power in the frontal regions as an indicator of cognitive control recruitment in high demanding cognitive control operations, such as, for example, performance monitoring in cognitive interference tasks (Nigbur et al., 2011). And, Jensen and Mazaheri (2010), who linked post stimulus alpha activity to attentional selection used to filter out task-irrelevant stimuli to focus attentional resources on task-relevant stimuli.

In the current study, EEG indices of brain activity showed correlations between alpha suppression, bilingualism, and ageing. This is illustrated in figure 7, and is seen as age increases, alpha suppression gets smaller, meaning that the difference between the two conditions decreases. What was seen in the analysis was that the subjects, irrespective of their behavioral patterns, rely more consistently on alpha power, and as they get older, are not losing access to alpha but instead maintain a base layer of alpha. Thus, an interpretation of the relation between MLD, increasing age and alpha suppression could be that increased levels of bilingualism, or more active bilingual language use over time, levels out the cognitive decline slope of ageing. Interestingly, alpha activity was extracted mainly from posterior regions, though also central. Thus, if alpha rhythms are generated in the sub-cortical brain structures, and as all participants were balanced bilinguals with a relatively early age of attainment, this could be in support of the BAPSS hypothesis (Grundy et al., 2017). This postulates that lifelong bilinguals, instead of experiencing a posterior to anterior shift with ageing, as in the PASA hypothesis (Davis et al., 2007), are able to maintain more efficient cognitive processing as they for a longer period of time uphold the recruitment of posterior regions in older age.

Moreover, it is thought that theta rhythms predominately come from frontal cortical activity (Grady et al., 1994). If theta rhythms generate in frontal regions, they are not at the point of cognitive reserve, that is, having to pull from different resources. Instead, what ends up happening is a sub-cortical to frontal shift with ageing, as with PASA. However, several models of bilingualism, though then particularly those for lifelong bilingualism, predict a shift in the opposite direction as a function of bilingualism, as for example, BAPSS. Hence, if alpha generates in the sub-cortex, and bilingualism is shifting your reliance to stay in the sub-cortex for attentional control demands, alpha would be expected in posterior regions with ageing due to lifelong bilingualism. The data of this study could therefore be interpreted as an indication of this. Nevertheless, the lack of theta significance is interesting but as there is a trending effect of MLD on theta power, a wider MLD range along with more statistical power could potentially result in more reliable results.

The explanation for the adaptation of cognitive systems as an effect of bilingualism is likely to somehow comprise EF processes (Bialystok & Craik, 2022; Bialystok, 2008; Green, 1998). However, the grounds for which these processes are involved are not clear. The working hypothesis is that both languages of a bilingual to some degree always remain active, thus, bilinguals need to engage some cognitive mechanism to monitor these two or more languages, ultimately leading to maintained domain-general cognitive abilities (Kroll et al., 2012). Inhibitory control, presents a view in which bilingualism constantly engages inhibitory control for target-like language production and this way trains the inhibitory mechanism, leading to a transfer effect of inhibitory control to other cognitive domains. However, this view of an inhibitory domain-general transfer effect cannot explain the ambiguous results in the literature, nor within group variations.

In contrast, attentional control relies on an adaptation of attentional systems, which does not lead to a higher quantity of attentional resources, but rather more efficient use of resources across domains involving attention (Bialystok, 2017). This way, individual experiences modify cognitive operations and their interrelated neural dynamics, however, the impact of attentional control adaptations may not be equivalent across all task domains (Bialystok & Craik, 2022). Therefore, what is seen with for example the use of the flanker task, is that it can potentially show group variations which may be a result of the task's attentional demands and/or the variable attentional control capacities of the subjects (Bialystok & Craik, 2022; Bialystok, 2017). The explanation for this variation according to the hypothesized attentional control mechanism, is that the neurocognitive adaptations of bilingual language experiences impact various domains in which attentional processes and operations are involved, however, how the adaptations manifest varies throughout the lifespan and can differ between tasks (Bialystok & Craik, 2022). This explanation of attentional control can also explain the results of this study, as bilingual experiences were found to modify neural oscillatory dynamics but were not found to have the same effect on reaction time data. Therein, provided that attentional systems are behind the effectiveness of cognitive processing operations (Bialystok & Craik, 2022), attentional control as mechanism for language control may explain how the constant use of attentional control can lead to more efficient use of attentional resources. A marker for this can be seen in how the efficient allocation of attentional resources does not dictate enhanced results of specific cognitive tasks, but instead a variability as part of a spectrum of processing outcomes in operations involving attentional control.

5.3 General discussion

The aim of the present study was to examine the potentially modulatory role of individual differences in bilingual experience on cognitive ageing at both a behavioral and neural level. First, in looking at behavioral flanker task data from congruent and incongruent trials, I explored the modulations of bilingual experiences on reaction time data relative to the cognitive ageing trajectory. Comparison of age, bilingual experiences, and reaction time revealed different patterns of cognitive control employment in relation to differential bilingual language engagement. I expected to find a decrease in the slowing of reaction time in participants with more balanced bilingual experiences, however, the results showed the opposite pattern, as more engagement with bilingual experiences predicted slower reaction times in ageing, whilst a lower engagement with bilingual experiences predicted a slowing of reaction time decline, or more efficient reaction times. In the framework of attentional control as proposed by Bialystok and Craik (2022), neurocognitive adaptations as the effect of bilingual language use are thought to manifest differently throughout the lifespan. There are also no specific tasks that bilinguals will perform better on, instead bilinguals enjoy more efficient and effective attentional resources, which aids the processes and functions in which attentional processes are involved. Thus, according to this framework, there is no guarantee that more balanced bilinguals will perform better on the flanker task. Moreover, young adults for example are not expected to perform better on simple executive functioning tasks overall, regardless of language experience. Therefore, this instance could also be a case of the older adults not yet having reached the state of which additional cognitive demands need to be recruited or strengthened for efficient processing. However, this still does not explain why participants with a lower multilinguistic diversity have a smaller effect of age on reaction time. I argue that this pattern likely is seen due to either the small variation of multilingual diversity across participants, or the result of insufficient statistical power, especially as the study only included a few participants representing the senior age group.

Second, in looking at electrophysiological indices of neural activity's interaction with age and bilingual experiences, the study provides evidence of trending effects in favor of language related neurocognitive adaptations in ageing. Most prominently, as predicted, one interpretation of the study suggests that active bilingual language use possibly helps maintain the recruitment of cognitive resources from posterior regions in ageing as hypothesized in BAPSS (Grundy et al., 2017). Posterior regions are believed to be responsible for motor function, therefore by keeping up this recruitment of posterior recourses in ageing the brain can make more efficient use of neural networks. In this study, this is seen through how ageing individuals with more bilingual experiences maintain levels of alpha power originating in posterior regions of the brain. However, theta power extracted from frontal and central regions were only trending in the interaction with age and language experiences. Again, this has been argued as a possible implication of a narrow multilinguistic diversity, as well as a statistical power issue. Looking at the mechanism behind this, BAPSS agrees with the hypothesized attentional control, which is believed to differentially impact cognitive processes in which attention in involved, leading to overall more efficient use of neural resources. Therefore, as the subjects were able to maintain their use of posterior regions for alpha in ageing, presumably leading to more efficient cognitive performance, attentional control remains a promising approach to investigate the underlying mechanism of bilingualism. Lastly, it is clear from the study that bilingualism should be considered dynamically in establishing the relationship between bilingualism and cognitive change in ageing.

5.4 Limitations and suggestions for further research

The present study is limited in that it only includes 20 participants, in which only about 15% represents the senior age range. This is likely to have caused a statistical power issue and has implications for the robustness of the results reported herein. The study is further limited in that all participants are fairly balanced in their degree of bilingual language use, resulting in a narrow MLD range which thus potentially does not provide the necessary variability to show any meaningful effects of degree of bilingual engagement on cognition. This is an implication of a common attitude of the Norwegian population, viewing personal bilingual status as a condition led by fluency. In relation to this study, it seemed as if only confident bilinguals were inclined to partake. Therefore, in moving forward, more effort should be put into encouraging all types of bilinguals to participate in research, regardless of language proficiency. And if necessary, develop methods to approach and attract those in which might not feel as confident in their second language use, but still happily engages in their second language for occasions such as travelling and holidays or for activities such as watching TV, listening to podcasts, and reading. This way, the relationship between cognitive ageing, bilingualism and task performance might be clearer.

Furthermore, Bialystok and Craik (2022) present a convincing case for a bilingual adaptation of attentional control. However, though the findings of this study could fit in with this framework, further research utilizing more complex tasks domains would be needed to fully understand the underlying mechanisms of this potential relationship. Therefore, just as bilingualism should be accounted for dynamically in research moving forward (DeLuca et al., 2019; Leivada et al., 2020), the case for attentional control calls for the same approach. Within this, adaptations of attentional control suggest differences in the relationship between individual bilingual experiences relative to a slope of different task demands, not merely congruent versus incongruent (Bialystok & Craik, 2022). Therefore, going forward, cognitive tasks should be manipulated to include a wider variety of task difficulties in which increasing difficulty levels could be tested against a variation of bilingual experiences.

6 Conclusion

The main findings of the study suggest that subjects with higher MLD, irrespective of behavioral patterns better maintain a base level of alpha in ageing. Alpha suppression signifies the allocation of attentional resources, thus, by upholding this reliance upon alpha, bilingual language engagement potentially works to level out the cognitive decline slope of ageing. Patterns within theta power also showed tendencies of modulatory effects of MLD, exhibiting more theta power with higher MLD. Behavioral data showed a bigger effect of age on reaction times in subjects with higher multilinguistic diversity. Arguably, attentional control as mechanism for bilingual language processing may explain why individual engagement in bilingual experiences were found to modify neural dynamics, without the same effect on the behavioral measures of the study. Therefore, conclusively, the present study supports the findings that individual differences in bilingual experiences have a modulatory effect on neurocognitive outcomes in ageing.

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Appendices

A,

Questionnaires

Language history questionnaire (LHQ3). Brain, Language, and Computation (BLC) Lab, The Hong Kong Polytechnic University @ 2022 Copyright https://blclab.org/lhq3/

Mini mental state exam (MMSE) Norwegian. Aldring og helse: Nasjonal kompetansetjenese. Aldring og helse, 2018. https://www.aldringoghelse.no/wp-content/uploads/2020/09/mmse-nr3-bokmal-komplett-utenglp.pdf

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Short form dietary questionnaire (SFFFQ). SFDietQuest. V1.0 December 2009.

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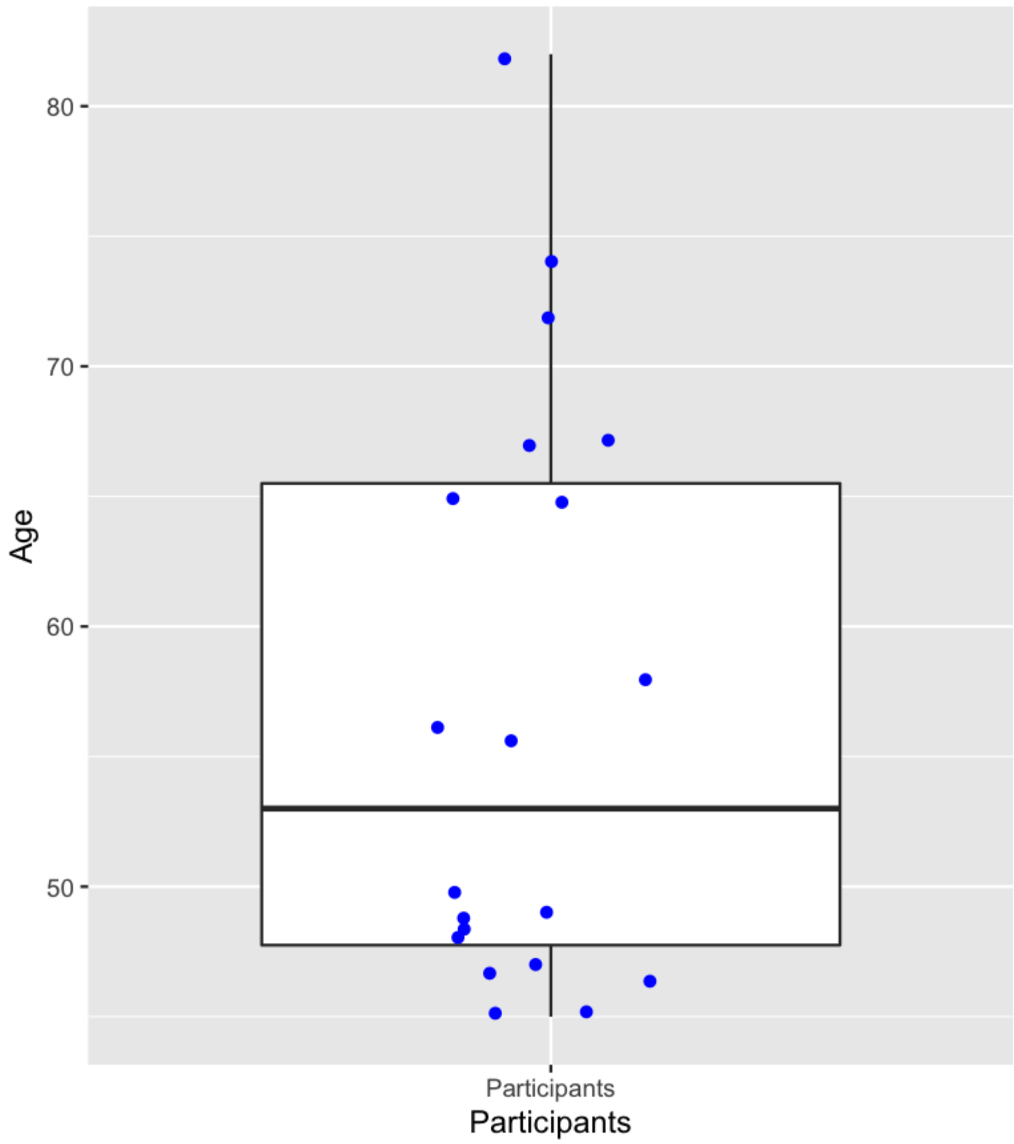
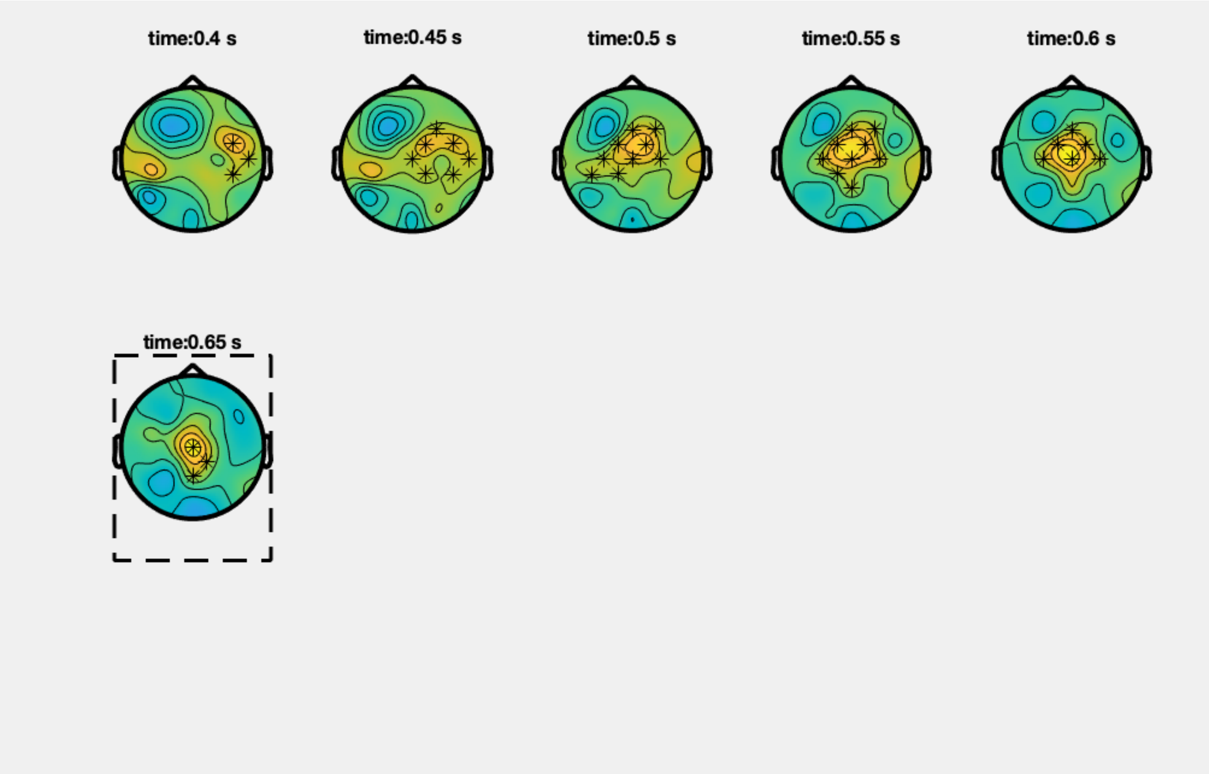
B,

Participant age distribution.



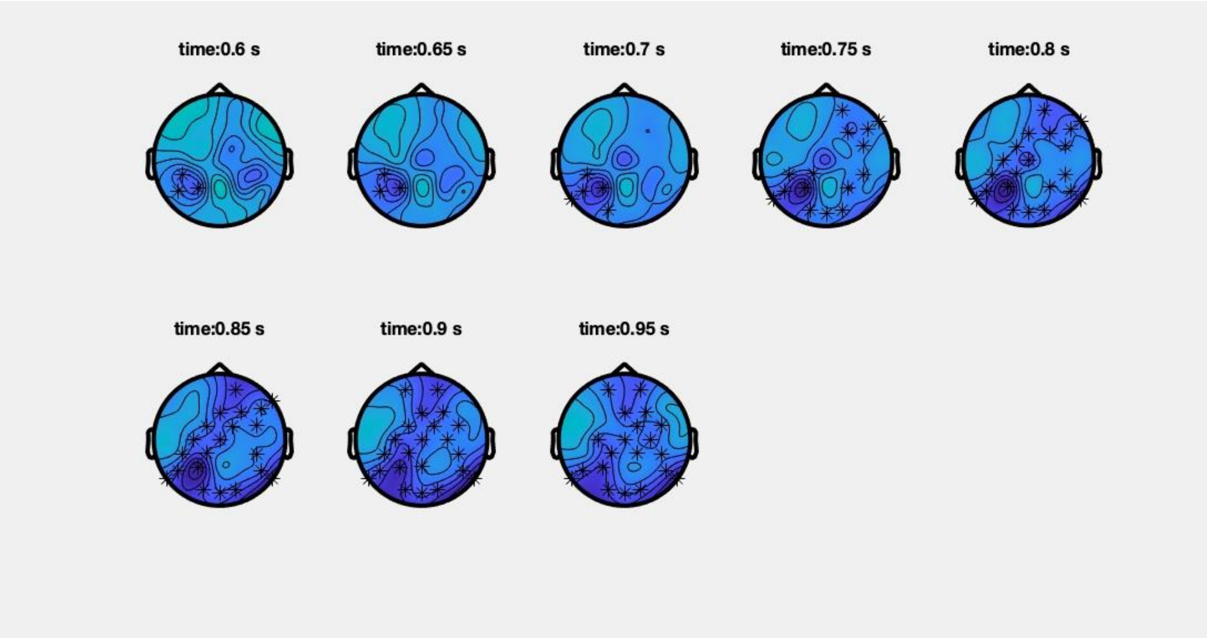
C,

Positive theta clusters.



D,

Negative alpha clusters.



E,

Distribution of flanker task reaction times.